Plug-in vehicles and the future of road infrastructure funding in the United States

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Abstract

In the United States, road infrastructure funding is declining due to an increase in fuel efficiency and the non-adjustment of fuel taxes to inflation. Legislation to tax plug-in vehicles has been proposed or implemented in several states. Those propositions are contrary to policies to promote fuel efficient vehicles. This paper assesses (1) the magnitude of the decline in federal fuel tax revenue caused by plug-in vehicles and (2) quantifies the revenue that could be generated from a federal plug-in vehicle registration fee. We find that the contribution of plug-in vehicles to the decline of the federal fuel tax revenue is at most 1.6% and the majority of the shortfall can be attributed to the non-adjustment of the fuel tax rate and the increase in vehicle fuel efficiency by 2040. An additional tax of $50-$200 per plug-in vehicle per year in the reference case would generate $188-$745 million in 2040 which represents an increase of 1.69% - 6.71% in federal fuel tax revenue compared to no tax. The lesson for policy makers is that plug-in vehicles do not contribute significantly to the funding shortfall in the short- and medium-run and a supplemental tax would generate a small percentage of additional revenue.

Keywords: Plug-in hybrid vehicles, battery electric vehicles, gasoline and diesel tax, fuel consumption, Highway Trust Fund

1 Introduction

Many countries rely on gasoline and diesel taxes to finance their road infrastructure. In the United States, the consumption-based tax revenue raised at the federal level contributes to the Highway Trust Fund (HTF)
which was established by the Highway Revenue Act of 1956 (DOT/FHWA, 1998). The current federal tax rates are $0.184 and $0.244 per gallon of gasoline and diesel, respectively. Taxes are also imposed on other fuels such as liquefied petroleum gas, liquefied natural gas, compressed natural gas, etc. (FHWA, 2014). In addition to the federal taxes, states collect gasoline and diesel taxes to fund local infrastructure projects. The current primary revenue-related issue for transportation infrastructure is the extent to which transportation construction and maintenance is tied to gasoline and diesel consumption. Transportation revenues have stagnated since 2001 and expenditures associated with road construction and maintenance have outpaced revenues (Kile, 2011; Ungemah et al., 2013). At least three factors have contributed to the stagnation in revenues. First, the general increase in fuel efficiency of conventional gasoline vehicles. Between 1980 and 2012, average fleet fuel efficiency increased from 15.97 to 23.31 miles per gallon (MPG) which represents a 30% reduction in fuel consumption of the average vehicle (U.S. DOT Bureau of Transportation Statistics, 2015). Second, the stagnation in annual vehicle miles traveled (VMT) can be explained by the recent economic recession (FHWA, 2012). While there may be an increase in VMT in future years, the extent of that increase is expected to be inconsequential (FHWA, 2012). Finally, gasoline and diesel taxes are set as a fixed amount per-gallon without being adjusted to inflation at the federal level and in most states, i.e., the real tax rate is declining over time. The last adjustment at the federal level occurred in 1993 and some states have not adjusted their per-gallon gasoline tax since 1961 (ITEP, 2014). This inflexibility of the tax base is responsible for an effective decrease of 30% in the federal fuel tax rate.

Given the erosion of the tax base, the HTF has suffered a decline in its balance and experienced significant funding shortfalls. Over the last seven years, lawmakers have had to transfer a total of $65 billion from the United States’ general fund to the HTF to keep it solvent (Cawley, 2013; Kile, 2015). To secure adequate infrastructure funding in the future given the continued funding shortfall, proposals have been made to increase the federal fuel tax (Kile, 2015), replace the fuel tax with a fee on vehicle miles traveled (VMT) (TRB, 2006; Schank and Rudnick-Thorpe, 2011; Duncan and Graham, 2013), or shift to state and local funding schemes (Goldman and Wachs, 2003). Given the need for new ways of funding road infrastructure, some states have identified plug-in vehicles, i.e., plug-in hybrid and battery electric vehicles, as a source of revenue and have started charging an additional annual registration fee for such vehicles.

States that charge a per-vehicle registration fee for alternative fuel vehicles are Colorado ($50), Georgia ($200), Idaho ($140), Nebraska ($75), North Carolina ($100), Virginia ($64), Washington ($100), and Wyoming ($50) (NCSL, 2015). Similarly, an “Electric Vehicle Plug-In Registration” for fully electric vehicles that “is not lower than $100” was proposed in Massachusetts (MA Legislature, 2014). According to the National Conference of State Legislatures, “states are also addressing concerns regarding the effect that the growing use of electric vehicles may have on funding for transportation infrastructure, which relies heavily on gasoline taxes” (NCSL, 2015). Washington State senator Mary Haugen stated that “electric cars will be
driving on the highways right along with all the other cars. […] We believe they should be paying their fair share” (Seattle Times, 2011). In the case of Washington State, the governor’s budget office estimates that the $100 fee would bring in $1.9 million for 2015-2017 budget cycle and that the overall Department of Transportation budget is $6.9 billion over the same budget cycle (Seattle Times, 2011). In North Carolina, the fee was expected to raise $160,000 in 2014 given an anticipated gap between infrastructure needs and revenue of $60 billion over 30 years (The News & Observer, 2014). At the federal level, the Developing a Reliable and Innovative Visions for the Economy (DRIVE) Act includes provisions to extend user fees to electric vehicles because “ownership of electric and alternatively fueled vehicles continues to constitute a larger percentage of users” and to “ensures all motorists pay their fair share” (EPW, 2015). Given the examples from Washington and North Carolina, there is little indication that policy makers should believe that electric vehicle fees can make up for the fuel tax revenue shortfall, yet policy proposals to charge fees are implemented or discussed in several states.

The funding model based on gasoline and diesel consumption is not viable in a world that, in the very long-run, will have transitioned away from internal combustion engines to mainly highly fuel efficient plug-in vehicles. Previous research suggests that state and federal fuel tax revenue, under various scenarios, could decrease by as much as 5% and 12.5% by 2020 and 2030, respectively (Hajiamiri and Wachs, 2010). The problem is, registration fees or taxes are contrary to policies intended to promote the use of plug-in vehicles; such vehicles have received considerable attention and funding due to concerns about energy independence, energy efficiency, and greenhouse gas emissions (EISA, 2007). The U.S. federal government provides income tax credits as high as $7,500 to incentivize the purchase of battery electric vehicles (Krause et al., 2013). Similarly, state and local governments provide credits or exemptions to sales taxes, excise taxes, registration fees, and parking fees (Gallagher and Muehlegger, 2011). Even with those incentives, the Energy Information Administration (EIA) estimates the share of plug-in vehicles in 2040 to be 1.71% and 5.14% in its baseline and most optimistic scenario, respectively (EIA, 2014).

Notwithstanding the need for a comprehensive change in policies with respect to infrastructure funding including all types of vehicles, we question policy makers introduction of a fee on plug-in vehicles that (1) is likely to have a small contribution to revenue because of the small market share, (2) is opposed to policies subsidizing plug-in vehicles, and (3) is fixed at a per-vehicle rate instead of a VMT rate as proposed by researchers. There is a lack of empirical evidence to suggest that these fees will adequately address the funding shortfalls in the future that have become increasingly apparent, and this paper aims to close that knowledge gap at the federal and, to a certain extent, state level. This paper focuses on the impact of the expected growth in the plug-in vehicle fleet within the context of fuel taxes that are not adjusted for inflation. Specifically, we extend the current research in this area in two ways: First, we consider the funding shortfall in the context of the continued practice of not adjusting fuel taxes to keep pace with the inflation and the
consequences of increased fuel efficiency. Second, we forecast how much federal revenue might be generated from an annual tax or registration fee on plug-in vehicles under the current sales projections to determine if such a tax could alleviate the expected funding shortfall. We show that the majority of the funding shortfall is due to the non-adjustment of fuel taxes and the increase in fuel efficiency. Little can be attributed to the growing use of plug-in vehicles; thus a registration fee would not alleviate the funding shortfall. Although the low impact of plug-in vehicles on road financing is not a surprise given the low adoption numbers, it is useful to quantify those impacts in this article to form a basis for policy discussions. Given the tension between the desire of policy makers to increase the use of alternative fuel vehicles and the funds needed for transportation infrastructure maintenance, the lesson we draw for decision makers is that, taking energy security and energy efficiency into account, at least in the short- to medium-run, policies to promote plug-in vehicles should be maintained. To meet environmental goals, a Pigouvian tax on fuel consumption is the appropriate tool but in the presence of increasing fuel efficiency will not satisfy highway funding needs. On the other hand, a VMT fee will cover the funding needs of highways in the long-run but does not achieve environmental goals since reducing fuel economy is not incentivized. Each goal should be achieved using the appropriate policy tool. Finally, there is the potential of having more plug-in vehicles on the road by 2040 than currently estimated by the EIA. Our paper explores some of the issues relevant to dealing with that possible outcome.

2 Methods

In this section, we describe the general model setup. Additional modeling information can be found in the Supplementary Information that is available online. The EIA’s 2014 Annual Energy Outlook (AEO) projections are our primary source of data to model the impact of plug-in vehicles on the current and future funding gap of the HTF as well as the effects of possibly taxing plug-in vehicles at the federal level. The EIA provides projections for a reference case which assumes current policies with a 2.4% average gross domestic product (GDP) growth rate between 2012 to 2040 and a $141 (in 2012 dollars) oil price by the end of the projection period (EIA, 2014). The EIA models an additional 29 scenarios for comparison to the reference case that reflect potential variations in policies, GDP growth, and oil price evolution. For our model, we selected data from 12 scenarios (including the reference case) that are directly related to the transportation sector (Figure 1). Building our simulation around the EIA scenarios allows us to analyze the sensitivity associated with different assumptions, such as oil price evolution, economic growth, or vehicle miles traveled.

In its projections, the EIA categorizes light-duty vehicles along two dimensions: vehicle type and technology. The vehicle type contains two categories: cars and light trucks. The technologies of interest to this paper are gasoline, diesel, E85, conventional gasoline hybrids, conventional diesel hybrids, 100 Mile Electric Vehicle (BEV100), 200 Mile Electric Vehicle (BEV200), Plug-in 10 Gasoline Hybrid (PHV10), and Plug-in...
Figure 1: Vehicle Stock Summary for the Analyzed Scenarios. The total number of battery electric vehicles (BEV100 and BEV200) and Plug-in Vehicles (PHV10 and PHV40) are summarized on the left axis and the number of gasoline vehicles is summarized on the right axis. The scenario “Extended Policies” assumes the extension of all existing tax credits including the tax credit of $7,500 for the purchase of qualifying plug-in vehicles that would otherwise be phased out after a manufacturer-specific sales quota is met.

40 Gasoline Hybrid (PHV40).\(^1\) We refer to the vehicles using the last four technologies as plug-in vehicles. All four types of plug-in vehicles are expected to grow the fastest with projected average annual growth rates of 13% for battery electric vehicles and 14.9% for plug-in hybrid vehicles between 2012 and 2040 (EIA, 2014). The technologies analyzed by the EIA that are not listed above are expected to have a share of less than 0.15% in 2040 and are thus not included in this analysis. We group cars and light trucks together in the conventional hybrid and plug-in vehicle categories because the share of light trucks is less than 7% for those technologies. Grouping the vehicles has the advantage that fewer parameters are necessary in the simulation part of our analysis.

The primary variables for our simulation model are gasoline and diesel prices, vehicle sales and stock,

\(^1\)The numbers 10 and 40 for the PHEV10 and PHEV40 refer to the all-electric range in miles before switching to gasoline.
vehicle miles traveled, and vehicle fuel economy. Projected gasoline and diesel prices as well as vehicle sales and stock (by vehicle type and technology) are directly available from the EIA projections. The vehicle miles traveled is only available by technology and not by vehicle type. Because we need the VMT by vehicle type for gasoline, diesel, and E85 cars, we assume an average annual VMT for cars and trucks of 10,614 and 14,596 miles in 2012, respectively (FHWA, 2011). For the subsequent years, we construct an index of the VMT by technology based on the EIA data and link the VMT index to the values in the base year. The calculation of the VMT for the other vehicles is available directly from the EIA. For the fuel economy in the first year of our simulation model, we take estimates from the U.S. DOT Bureau of Transportation Statistics (2015) and Al-Alawi and Bradley (2013). For the fuel economy of conventional gasoline vehicles, we assume 23.3 and 17.1 MPG for cars and trucks, respectively (U.S. DOT Bureau of Transportation Statistics, 2015). For conventional hybrids, we use a fuel economy of 43.7 and 40.6 MPG for highway and urban driving, respectively (Al-Alawi and Bradley, 2013). For plug-in hybrid vehicles, the utility factors for PHV10 and PHV40 mid-sized vehicles are taken from Al-Alawi and Bradley (2013). The utility factor for urban and highway are 0.32 and 0.12 for PHV10 and 0.79 and 0.41 for PHV40. Assuming highway driving of 45%, we calculate a weighted utility factor of 0.1829 and 0.5575 for PHEV10 and PHEV40, respectively. The highway and urban driving MPG for PHEV10 in charge sustaining mode is 40.75 and 45.40, respectively. The values for the PHEV40 are 41.65 and 48.4 MPG. For the diesel consumption of the current fleet, we assume that the ratio of gasoline to diesel fuel economy is the same as for new cars sold which is reported by the AEO. We then calculate the implicit diesel fuel economy of vehicles currently on the road that match the AEO projections. This results in a diesel fuel economy of 44.15 and 34.26 MPG for cars and light trucks, respectively. For the subsequent years, we index the future evolution of the fuel economy to the fuel economy implicit by the number of vehicles by technology and the consumption of fuel by technology. The data provided in the 2014 AEO for E85 led to unrealistically high estimates for the fuel economy. Thus we relied on the fuel economy being 30% their conventional counterparts. The fuel economy remains exogenous throughout our model runs.

Based on the stock of vehicles, the vehicle miles traveled, and the fuel economy, we model the consumption of gasoline, diesel, and E85 for the vehicles in our model as a function of (1) vehicle stock, (2) VMT per year, and (3) fuel economy. The gasoline consumption for cars \((gas_c)\), trucks \((gas_t)\), conventional gasoline hybrids \((hyg)\), and plug-in hybrid vehicles \((PHV10\) and \(PHV40\)) is written as

\[
C_{gas} = \sum_{i \in \{gas_c, gas_t, hyg\}} S_i \cdot \frac{VMT_i}{MPG_i} + \sum_{j \in \{PHV10, PHV40\}} S_j \cdot \frac{VMT_j \cdot uf_j}{MPG_j}
\]

where \(uf_j\) refers to the utility factor dividing the energy consumption of plug-in hybrid vehicles into a charge sustaining and charge depleting mode. The charge sustaining mode refers to the condition where plug-in
hybrids use gasoline to operate. In the charge depleting mode, i.e., depleting its battery, the plug-in hybrid vehicle uses the electric motor only. The equations for the consumption of diesel and E85 are written as

\[
C_{tdi} = \sum_{i \in \{tdi, tdi, hyd\}} \frac{S_i \cdot VMT_i}{MPG_i}
\]

\[
C_{E85} = \sum_{i \in \{E85, E85\}} \frac{S_i \cdot VMT_i}{MPG_i}
\]

We assume that the vehicle miles traveled for vehicle type \(j\) is a constant elasticity function of the price of fuel type \(i\), i.e., gasoline, diesel, or E85 depending on the vehicle:

\[
VMT_j = \alpha_j (p_i + t_i)^{\eta_i}
\]

The VMT elasticity with respect to the price of gasoline varies from -0.05 to -0.4 (Parry and Small, 2005; Greene, 2011). We assume a value of -0.225 but include the lower and upper values in the sensitivity analysis. Thus, on the demand side of fuel consumption, the endogenous variables are the VMT and the fuel price paid by the consumer which include the fuel tax.

The supply side for gasoline, diesel, and E85 is modeled as a simple constant elasticity supply function.

\[
M_i = \alpha p_i^{\beta_i} \text{ for } i \in \{gas, tdi, E85\}
\]

The supply of gasoline is relatively inelastic and estimates range from 0.2 to 0.5 (Rajagopal et al., 2007, 2009; de Gorter and Just, 2009; Coyle et al., 2012). We use the average value of 0.35 but include the upper and lower bounds in the sensitivity analysis.

Given our model and parameters, we run a baseline that leaves all variables at their status quo values. When compared with the values from the 2014 EIA reference case, the consumption of gasoline and diesel are within 1.5% and 5.6%, respectively. Based on the data from the 2014 AEO, we calibrate the simulation model such that all markets are in equilibrium in each scenario and each year at the beginning of the simulation in the absence of any stock or fuel tax modifications. To determine the effects of plug-in vehicles on fuel tax revenue in the simulation model, we vary the vehicle stock and the fuel tax rate. Variations in the vehicle stock and the tax rate results in new equilibrium prices for gasoline, diesel, and E85 and thus, influences the VMT as well. Note that other factors affecting VMT, such as economic growth or policies, are already taken into account by the projections from the EIA.
Figure 2: Evolution of the Federal Fuel Tax Revenue 2011-2040. The baseline refers to the reference case of the EIA. The “Real Fuel Tax Rate” scenario assumes a gasoline and diesel tax of $0.184 and $0.224 per gallon remaining constant in real terms over the projection period. The lower bound refers to the “Low Economic Growth” scenario and the upper bound refers to the “Low Oil Price” scenario.

3 Results

To evaluate the contribution of the declining real fuel tax rate, the increase in fuel efficiency, and the increase in plug-in vehicles on tax revenue, we assess three cases. For each of the 12 selected EIA scenarios, we (1) keep the gasoline and diesel tax rates constant in real terms (“Real Tax”), (2) assume all plug-in vehicles to be gasoline cars (“No PV”), and (3) index the fuel taxes to the fuel economy (“MPG Tax”). We also report the results of combining those scenarios.

To assess the revenue potential of an additional registration fee on plug-in vehicles, we impose three different levels of annual taxes that covers the aforementioned range of state legislation, i.e., $50, $100, and $200. In 2012, the average gasoline car driver pays $83.72 in federal taxes according to our model.

3.1 Contribution to Fuel Tax Revenue Decrease

Our model indicates that based on the 2014 EIA reference case projections, the annual federal fuel tax revenue will decrease from $25.23 billion dollars in 2012 to $11.09 billion in 2040. This represents a decrease of 56.03% which can be attributed to the gains in fuel efficiency, the decline in the real fuel tax rate, and the increase in alternative fuel vehicles. The smallest and largest decreases are observed in the low oil price scenario (decrease of 44.6%) and the low economic growth scenario (decrease of 73.8%). Given the decrease in revenue across all projections, the question is under what conditions and policies can the stream of revenue
Table 1: Contribution of decreasing real fuel tax rates and plug-in vehicles on the federal fuel tax revenue in 2040. The “baseline” refers to the gasoline and diesel tax revenue in the absence of any changes. The additional revenue compared to the baseline refers to the revenue generated from keeping the fuel tax rates constant in real terms and from assuming all plug-in vehicles being gasoline cars.

If the federal fuel taxes were adjusted for inflation, the gasoline and diesel tax would remain at $0.184 and $0.224 per gallon in real terms. The results for this scenario can be found in the column “Real Tax” in Table 1. Figure 2 shows that there would be significant additional revenue in the reference case at the end of the projection period in 2040. For all other EIA scenarios, additional revenue varies between $7.54 and $10.36 billion in 2040. Despite the additional revenue, the overall trend in gasoline and diesel tax revenue is still declining between 9.2% and 38.5% compared to 2012 levels.

The column “No PV” assesses the case where fuel taxes are not adjusted to inflation and all plug-in vehicles as gasoline cars. In the EIA reference case, the share of plug-in vehicles is highest for the PHEV40 at 0.62%. Thus, we would expect that the impact of plug-in vehicles in general is small. It might be argued that buyers of plug-in vehicles would most likely switch to conventional hybrids if they had to. Though, in this analysis, we are interested in the upper bound. As can be seen in the column “No PV” (Table 1), the additional revenue is negligible even under the assumed case that all plug-in vehicles are switching to the

<table>
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<tr>
<th>EIA Scenario</th>
<th>2040</th>
<th>Real Tax</th>
<th>No PVs</th>
<th>MPG Tax</th>
<th>Real Tax &amp; No PVs</th>
<th>MPG Tax</th>
<th>Real Tax &amp; No PVs</th>
<th>MPG Tax</th>
<th>No PVs &amp; MPG Tax</th>
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Percent change in 2040 compared to baseline

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<th>Percent</th>
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<th>2040</th>
<th>2012</th>
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<td>158.3%</td>
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<td>GHG Price $25</td>
<td>78.4%</td>
<td>0.6%</td>
<td>58.5%</td>
<td>79.4%</td>
<td>182.2%</td>
<td>59.4%</td>
<td>183.3%</td>
<td></td>
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<tr>
<td>GHG and Low Gas Prices</td>
<td>73.3%</td>
<td>0.5%</td>
<td>54.7%</td>
<td>74.1%</td>
<td>167.7%</td>
<td>55.5%</td>
<td>169.0%</td>
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</tr>
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</table>
gasoline car category. The biggest change in revenue would be under the “Extended Policies” scenario which keeps the tax credit of up to $7,500 for battery electric vehicles in place resulting in 10.47 million plug-in vehicles as opposed to 3.76 million in the baseline. But even in this case, the additional revenue would only amount to 1.6% more than in the presence of plug-in vehicles.

For the third case, the effect of indexing the tax rate to fuel economy is similar to keeping the fuel taxes constant in real terms (Table 1). Although, the additional revenue is less when the fuel tax is linked to fuel efficiency rather than inflation. Hence, in figure 2, we have included the line for the combined scenario, i.e., keeping fuel taxes constant in real terms and indexing the tax rate to the evolution of the fuel economy. As can be seen, the resulting federal fuel tax revenue is driven by the increased stock in light-duty vehicles over the projection period.

Although the impact on fuel tax revenues is substantial, the impact on gasoline prices is moderate and could range from $0.04 and $0.07 (Table 2). The price impact for diesel is similar and can be found in the online Supplementary Information. Note that the “Extended Policies” would shift a significant number of plug-in vehicles into the gasoline car category. This would increase the demand for gasoline and consequently would raise the price of gasoline by $0.24. From our extended projections, it is clear that the revenue increase from eliminating plug-in vehicles is minimal. In other words, plug-in vehicles can be expected to have a small effect on the base of revenue dedicated to transportation infrastructure. Our results suggest that plug-in vehicles do not significantly contribute to the decline of gasoline and diesel tax revenue. In fact, it is clear from our projections that the real tax may alleviate part of the impact of the eroding tax base.

### 3.2 Additional Tax on Plug-in Vehicles

Our second research question assesses the additional revenue that could be generated from a registration fee on plug-in vehicles. There are two possible ways to levy the fee: Either, existing cars are grand-fathered in and the fee is collected only from new plug-in vehicle sales, or the fee is applied to all plug-in vehicles on the road, i.e., also those in service at the beginning of the projection period. We present the results for the later scenario because the stock of vehicles in service is low relative to the stock at the end of the projection period and thus, the differences between the two cases is small. To determine the effect of the registration fee on sales, we use the projected prices of the “mid-sized” cars for the four plug-in vehicles of interest. The additional revenue generated for the $50, $100, $200 per year plug-in vehicle tax is summarized in figure 3. In the reference case, levying a $50, $100, $200 tax on plug-in vehicles leads to a 1.69%, 3.37%, and 6.71% increase in revenue above the baseline, respectively. The smallest increase in revenue is observed for the low oil price case where the increase ranges from 0.91% to 3.63%. For the extended policies, this increase ranges from 5.03% to 19.96%. The additional revenue has two components: First, the direct effect of collecting the tax from plug-in vehicles, and second, the additional fuel tax revenue from consumers switching to gasoline
<table>
<thead>
<tr>
<th>EIA Scenario</th>
<th>2040</th>
<th>Tax</th>
<th>PVs</th>
<th>MPG</th>
<th>Tax &amp; PVs &amp; MPG</th>
<th>Tax &amp; MPG</th>
<th>PVs &amp; MPG</th>
<th>Total</th>
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<td>3.90</td>
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<td>0.06</td>
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<td>0.10</td>
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</tr>
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<td>High Economic Growth</td>
<td>4.02</td>
<td>0.04</td>
<td>0.07</td>
<td>0.04</td>
<td>0.11</td>
<td>0.11</td>
<td>0.11</td>
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<td>Low Economic Growth</td>
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<td>0.02</td>
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<td>0.13</td>
<td>0.09</td>
<td>0.19</td>
</tr>
<tr>
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<td>5.04</td>
<td>0.05</td>
<td>0.12</td>
<td>0.04</td>
<td>0.18</td>
<td>0.12</td>
<td>0.16</td>
<td>0.25</td>
</tr>
<tr>
<td>Low Oil Price</td>
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<td>0.04</td>
<td>0.03</td>
<td>0.04</td>
<td>0.07</td>
<td>0.10</td>
<td>0.06</td>
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<tr>
<td>Extended Policies</td>
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<td>0.19</td>
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<td>0.24</td>
<td>0.12</td>
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<td>High Oil and Gas Resources</td>
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<td>0.05</td>
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<td>High VMT</td>
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<td>0.07</td>
<td>0.04</td>
<td>0.11</td>
<td>0.11</td>
<td>0.10</td>
<td>0.18</td>
</tr>
<tr>
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<td>0.05</td>
<td>0.06</td>
<td>0.04</td>
<td>0.11</td>
<td>0.11</td>
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<td>High Demand Technology</td>
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<td>0.19</td>
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<tr>
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<td>0.08</td>
<td>0.04</td>
<td>0.13</td>
<td>0.12</td>
<td>0.12</td>
<td>0.20</td>
</tr>
<tr>
<td>GHG and Low Gas Prices</td>
<td>3.68</td>
<td>0.05</td>
<td>0.06</td>
<td>0.04</td>
<td>0.10</td>
<td>0.11</td>
<td>0.09</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Table 2: Change in gasoline prices due to real fuel tax rates and plug-in vehicles. The “baseline” refers to the gasoline and diesel tax revenue in the absence of any changes. The additional revenue compared to the baseline refers to the revenue generated from keeping the fuel tax rates constant in real terms and from assuming all plug-in vehicles being gasoline cars.

cars instead of plug-in vehicles. For a $100 fee, the additional revenue would be $255 million in the low oil price scenario and $1,041 million in the “Extended Policies” scenario. Note that the revenue from the additional gasoline cars purchased as a result of plug-in vehicle price increases is small compared to the revenue generated directly from the tax.

3.3 Sensitivity Analysis

Differences in our results in the previous sections are largely driven by the EIA scenarios in terms of economic growth, oil prices, vehicle miles travelled and policies. In this section, we focus on parameter choices that are outside the scope of the EIA models. We conduct a sensitivity analysis to assess the variability of our results based on key parameters: (1) supply elasticities with respect to gasoline, diesel, and E85, (2) VMT elasticity, (3) plug-in vehicle price elasticity, and (4) discount rate. Figure 4 summarizes the additional revenue in 2040 for the reference case when VMT elasticities and the supply elasticities of gasoline, diesel, and E85 are set at their upper and lower bounds. The difference in revenue is less than 0.5% in all cases.
Figure 3: Taxing Plug-in Vehicle Stock and Additional Revenue in 2040

Figure 4: Results of the sensitivity analysis with respect to fuel supply elasticities and vehicle miles traveled elasticities
The Supplementary Information includes the detailed results for the sensitivity analysis with respect to the plug-in vehicle price elasticity and discount rate. As price elasticity decreases, fewer buyers are dissuaded from a higher price for plug-in vehicles. A higher discount rate has a similar effect because buyers discount the future more heavily which lowers the additional cost of the plug-in vehicles at the beginning. The change in revenue is less than $0.819 million in all cases. Our results are very stable given the parameters chosen for our simulation model. Although the different scenarios assessed by the EIA, especially the “Extended Policies” scenario have a significant effect on the tax revenue. Despite those effects being substantial in some cases, they are small compared to the loss of revenue associated with the unadjusted gasoline and diesel taxes.

Our main result that plug-in vehicles do not contribute much to the funding shortfall and that levying a tax or registration fee will not generate significant additional revenue is relatively stable across the scenarios. The sole exception is the “Extended Policies” scenario which contributes about twice as much to the funding shortfall than the second most influential scenario (“High Oil Price”) but at a relatively small scale, i.e., 1.6% versus 0.8%. All of our scenarios involving modifications with respect to plug-in vehicles policies are trumped by the non-adjustment of the fuel tax rate and the increase in fuel economy. Table 1 underlines the importance of assumptions with respect to the evolution of the oil price and economy growth which are the most important drives in determining the overall level of the HTF.

4 Discussion

The United States currently relies on gasoline and diesel taxes to fund federal road infrastructure. Based on our research questions and the results, several other issues merit further consideration. Those are (1) how do other countries finance their infrastructure, (2) what is the impact at the state level, (3) how much road damage is done by plug-in vehicles, and (4) what alternative funding mechanisms are available and who would pay for those alternatives.

Currently, most European countries favor a system much like the United States when it comes to collecting revenue for their roads from the vehicles that use them. France, Germany, Spain, and the United Kingdom all tax gas and diesel. Those countries also use registration fees and tolls as supplemental sources of revenue. Those fees and tolls are in place to help supplement revenues when the gas tax revenue fluctuates. Gomez and Vassallo (2013) review highway use taxes and fees across Europe and the United States between 2004 and 2009 and report that Europeans pay on average about three times what each United States citizen pays to use their national interstates. The average United States citizen pays around $450 per year in the form of gas tax, tolls, registration, and purchase taxes compared to $1,300 in France, $1,275 in Germany, and $1,400 in the United Kingdom. Interestingly, the European drivers from the nations highlighted earlier still have a majority of their annual user fee coming from the gas tax: France (76%), Germany (88%), United Kingdom
(74%), compared to the United States (45%). The stark difference is that the European citizens pay more in separate fees, tolls, registration, and purchase taxes, than the average United States citizen pays even when all taxes and fees are combined.

Some European countries such as France have begun to completely remove their governments from the maintenance of highways (Albalate et al., 2009). Starting in the 1960’s, France began contracting with private companies to build new highways. France also began to sell off its existing national highways, allowing private companies to raise the necessary revenue, via toll, to maintain the infrastructure. A user fee based on distance and weight charges drivers not only based upon use, but also upon calculations of how much impact they have on roadways. In this system, drivers have a vested self-interest in driving a lighter, higher MPG vehicles, as this will save them money not only on the highway tolls, but on the gas tax as well.

This paper assesses the impact of an an increase in plug-in vehicles on road infrastructure funding at the federal level. At the state level, the situation is comparable to the federal situation, in the sense that a significant number of states do not adjust their fuel taxes on a regular basis (ITEP, 2014). We hypothesize that the impact of plug-in vehicles at the state level is as small as it is at the federal level in relative terms. Imposing an additional registration fee at the state level will likely have a very small impact on government finances coming from fuel tax revenue.

Our research questions are based on the assumption that there is a perceived inequality of infrastructure funding because plug-in vehicles contribute to the wear and tear of roads, yet do not contribute to the cost of infrastructure maintenance. One approach to determine how much plug-in vehicles should pay is to assess their contribution to road damage when compared to other vehicles. In 1960, the American Association of State Highway and Transportation Officials (AASHO) undertook the largest study of its kind in regards to the impact different vehicles have on the highways they use (TRB, 2007). The AASHO study concluded that while the weight of a vehicle contributed to how much it impacted the highway, the more important figure was the weight bearing down on each axle. Therefore, a vehicle with an even weight distribution would do less damage than one that had most of its weight bearing down on one axle. The study completed by the AASHO also found that the damage caused by vehicle weight increased exponentially, specifically to the fourth power. This became known as the Fourth Power Rule; stating that the difference in wear on a highway could be expressed by looking at the weight differences between vehicle axles. Recent studies have shown that the value can range between 3.6 to 7 depending upon a myriad of factors. Thus, these new studies have shown that 4 is a safe number to work with when working in generalities concerning overall road impact (Hjort et al., 2008; Anani and Madanat, 2010a,b). Plug-in vehicles are comparable in weight to their conventional counterparts. Even with the small discrepancies in weight, the damage imposed by plug-in vehicles is roughly the same as standard gasoline vehicles. The fourth power rule suggests that semi trucks exert an extraordinary amount of stress and damage on highways in comparison to other passenger
vehicles. A question for future research would be to assess how the damage done by large trucks compares to their contribution to the fuel tax, given the amount of miles traveled by those vehicles.

Any discussion on how to finance the road infrastructure in the future is complicated by multiple aspects. It could be argued that the public in general and not just drivers benefits from roads and thus, a case might be made that non-drivers should contribute to the construction and maintenance of roads. Currently, fuel taxes in the U.S. are based on the benefit principle, i.e., people using the road and consuming the service should be those who pay for the service (Duncan and Graham, 2013). Remaining with this principle, previous literature has focused on alternatives such as mileage fees, i.e., a fees dependent on the number of miles traveled, toll roads, and toll lanes (TRB, 2006; Zhao et al., 2015). A study by the Transportation Research Board suggests that future taxation should be based on mileage, road, vehicle characteristics, and traffic conditions (TRB, 2006). Parry and Small (2005) include the cost of externalities, congestion, and accidents as well in calculating the optimal tax. Given the aforementioned list of what should be taken into account when calculating the optimal user fee, it becomes clear that the current registration flat-rate for plug-in hybrid vehicles only partially covers those attributes because it assumes that every plug-in vehicle and every driver is identical. We note that battery electric vehicles have lower VMT than conventional gasoline vehicles and thus, should pay a lower rate than the average gasoline driver (Al-Alawi and Bradley, 2013; EIA, 2014).

5 Conclusions and Policy Implications

The revenue of the Highway Trust Fund has been declining over recent years. That decline is primarily due to two factors: the non-adjustment of fuel taxes to inflation and the increase in fuel economy. In the long-run, the United States should shift its road infrastructure funding away from gasoline taxes to an alternative system which, as most research suggest, should be based on vehicle miles traveled. In the meanwhile, policy makers at the state and federal level argue that plug-in vehicles should pay registration fee to compensate for the fact that those vehicles use the roads but do not contribute to their construction and maintenance. In this paper, we analyze the contribution of plug-in vehicles to the decline of fuel tax revenue and find that the decline is minimally attributable to plug-in vehicles and any annual plug-in vehicle tax would have a small fiscal impact. In addition, those fees undermine the United States’ goal for energy security and a sound environmental policy.

This paper shows that an increase in the federal fuel tax rate would generate significantly more revenue than the tax on plug-in vehicles. In addition, any discussion with respect to plug-in vehicles needs to analyze the amount of damage done by those vehicles. The taxes implemented or proposed for plug-in vehicles refer to issues of “fairness” in most cases. The “Fourth Power Rule” shows that the plug-in vehicles exert as much wear and tear on the highways as do their gasoline counterparts. It is important to ensure that owners of plug-in vehicles are paying their fair share into the Highway Trust Fund. It could be argued that
a fee on plug-in vehicles is a first step in moving away from infrastructure funding based on gasoline and diesel consumption. But the fee on plug-in vehicles is neither based on the amount of miles those vehicles travel nor does it make a large impact on the revenue in the short- to medium-run. In addition, those fees run against policies that subsidize plug-in vehicles. If fairness is the ultimate goal, then there might be a need to reevaluate how much semi-trucks are paying into the fund as well given their weight and axles. Policies aimed at creating fairness for the use of the highways would need to potentially reconsider how much each vehicle type is paying into the system. European countries specifically have many different means of collecting revenue. Therefore, while their plug-in vehicle sales should continue to increase along with the United States, they still have the means of collecting some revenue from those vehicles; especially in France where there toll system is based on a tiered system tailored toward vehicle type. As the Highway Trust Fund projections continue to decline, action will eventually need to be taken on stabilizing the fund for the long term; however, levying a tax on plug-in vehicles alone will not adequately produce the revenue adequate for that stabilization.

6 Acknowledgements

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